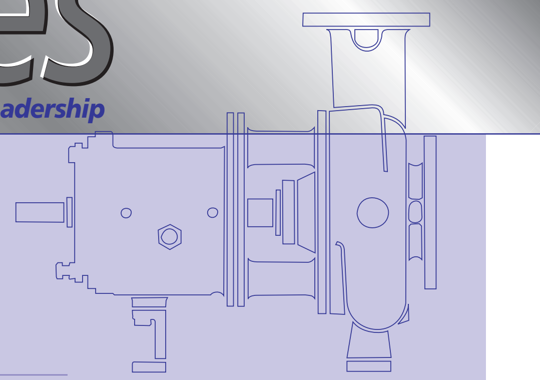
PumpLines
Innovation...Technology...Leadership
FALL 2001



Pump Reliability -

Correct Hydraulic Selection Minimizes Unscheduled Maintenance

Allan R. Budris, Director Product Development
Eugene P. Sabini, Director Technology
R. Barry Erickson, Vice President Technology
ITT Industrial Pump Group

Recently, significant attention has been given to the life cycle cost of owning a pump. Major components of the cost of ownership are initial cost, installation cost, operating cost, and maintenance cost. In process plants it has been found that under many circumstances the cost of unscheduled maintenance is the most significant cost of ownership. Although numerous papers have been presented on the subject of pump reliability, that literature primarily addresses mechanical means of improving reliability. The results of this attention to the mechanical issues as been a marked increase in the "Mean Time Between Repair" (MTBR) for process plants. This has been achieved largely through improved installation practices, and increased attention to operating procedures.

Efforts such as these will continue to yield improvements in MTBF, but will be limited in potential unless a holistic approach is used. Such an approach would give more attention to the best hydraulic fit to optimize reliability. There are four basic hydraulic selection factors which can have a significant affect on pump reliability. They are Pump Speed, Percent of Best Efficiency Flow, Suction Energy and NPSH Margin Ratio. These last two factors have further been combined into an NPSH Margin Reliability Factor (NPSH-RF), which has been shown to be reasonably effective in predicting the reliability of High Suction Energy pumps.

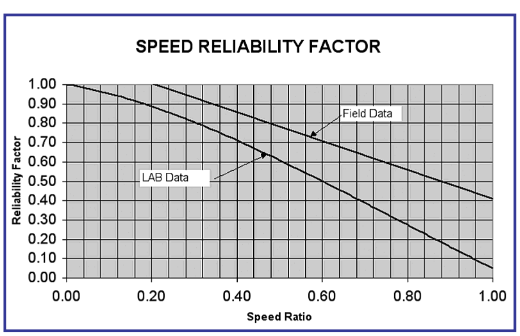


Figure 1.

The Laboratory reliability factors presented here [1] are based on correlation of the Block and Geitner [2] reliability factors with laboratory pump bearing frame oil temperature, and vane pass vibration tests on 3 API (end suction) pumps, plus published mechanical seal face and abrasive wear rates.

The field test reliability factors presented are derived from curve fits (trend lines) of Mean Time Between Repair data, on 71 ANSI and 48 split case pumps, in two process plants. There was much scatter of the data, due to the fact that the records were not cleansed of failures caused by factors other than hydraulic selection, such as human error, difficult to handle liquids, system interactions, or the mechanical design of the pumps. The duty cycles (operating times) varied between pumps, especially where pumps were on standby service. Also, the pumps were not always operated at the conditions of service analyzed. Despite the resulting large scatter in the data, definite trend lines could be and were developed, on the strength of the large number of pumps evaluated.

OPERATING SPEED:

Operating Speed affects reliability through rubbing contact, such as seal faces, reduced bearing life through increased cycling, lubricant degradation and reduced viscosity due to increased temperature, and wetted component wear due to abrasives in the pumpage. Operating Speed also increases the energy level of the pump, which can lead to cavitation damage.

Figure 1 compares the API-610 pump laboratory reliability predictor test results with the reliability trend line from actual MTBR data on 119 actual process pumps, as a function of the ratio of the actual to maximum rated pump speed. The Reliability factor for the field test data was based on zero pump repairs in a 48 month period, which was assumed to be equal to a MTBR of 72 months. Both curves show a marked increase in reliability with reduced speed.

continued on page 2

IN THIS ISSUE:

View this issue and previous issues of ***PumpLines*** *on our website at* ***www.gouldspumps.com***

Goulds Pumps
ITT Industries
Engineered for life

Pump Reliability...

continued from page 1

PERCENT BEST EFFICIENCY FLOW RATE (Flow Ratio):

The Flow Ratio affects reliability through the turbulence that is created in the casing and impeller as the pump is operated away from the best efficiency flow rate. As a result, hydraulic loads, which are transmitted to the shaft and bearings, increase and become unsteady. Also, the severity of these unsteady loads can reduce mechanical seal life. Operation at reduced flow rates that put the pump into its recirculation mode can also lead to cavitation damage in High Suction Energy pumps. Refer to ANSI/HI 9.6.3 [5] for more guidance on the allowable operating region for centrifugal and vertical pumps.
The field data to laboratory reliability comparison for the Flow Ratio is presented in figure 2. The field data is, however, only based on the 48 split case pumps, since no definitive trend line could be established from the ANSI plant data. Also, for trend purposes, the 1.00 Field Reliability Factor is based on a MTBR of 52 months. Correlation between the field and laboratory data is good in the normal operating range, with the maximum reliability occurring around 90 percent of the best efficiency flow rate.

SUCTION ENERGY:

Suction Energy is another term for the liquid momentum in the suction eye of a pump impeller, which means that it is a function of the mass and velocity of the liquid in the inlet. Suction Energy, as originally approximated by Budris and Mayleben [3], is defined as follows:

Suction Energy (S.E.) = D_e x n x S x s.g. Equation (1)

Where:

- D_e = Impeller Eye Diameter (inches)
- N = Pump Speed (RPM)
- S = Suction Specific Speed (RPM x $(GPM)^{.5}$ / $(NPSHR)^{.75}$)
- s.g. = Specific Gravity of Liquid pumped

Since the suction energy numbers are quite large, the last six digits are normally dropped (S.E. x E6). It should be noted that, if not readily available, the Impeller Eye Diameter can be approximated as follows:

End Suction Pump: D_e = 0.9 x Suction Nozzle Size

Split Case/Radial Inlet Pumps:
D_e = 0.75 x Suction Nozzle Size

Budris and Mayleben [3] have also proposed distinct gating values for High and Very High Suction Energy, for End Suction and Radial Suction (also know as split case or double suction) pumps, based on the analysis of hundreds of pumps from several manufacturers.

Start of High Suction Energy:
- End Suction Pumps: S.E. = 160 x 10^6
- Split Case/Radial Inlet Pumps: S.E. = 120 x 10^6

Start of Very High Suction Energy:
- End Suction Pumps: S.E. = 240 x 10^6
- Split Case/Radial Inlet Pumps: S.E. = 180 x 10^6

The above definition of Suction Energy (Equation (1)), and "High" and "Very High" gating values are consistent with values presented in ANSI/HI 9.6.1 [4].

Pumps with values of suction energy below these values are considered to have low suction energy. Generally speaking, Low Suction Energy pumps are not prone to noise, vibration or damage from cavitation. However, there could be detrimental effects on mechanical seals from the air or vapors which may be liberated from the liquid during the formation of the cavitation bubbles, under low NPSH Margin conditions (below 1.1 – 1.3 NPSH Margin Ratio).

Figure 3 is based strictly on the field data for 77 ANSI and Split Case pumps, with the 42 Low suction Energy failures (below 48 months) being deleted, because it is unlikely that these failures were caused by factors related to Suction Energy, mainly cavitation. Here also, a 1.00 Reliability Factor equates to no failures in 48 months, or a MTBR rate of 72 months. The trend is unquestionable, with higher suction energy pumps requiring the most frequent repairs.

NPSH MARGIN:

NPSH Margin Ratio is defined as the NPSH Available to the pump by the application, divided by the NPSH Required by the pump. By Hydraulic Institute definition, the NPSHR of a pump is the NPSH that will cause the total head to be reduced by 3%, due to flow blockage from cavitation vapor in the impeller vanes. NPSHR is by no means the point at which cavitation starts. That level is referred to as incipient cavitation. It can take an NPSHA of from 2 to 20 times NPSHR to fully suppress cavitation within a pump, depending on pump design and Flow Ratio (percent bep). The higher values are normally associated with high suction energy, high specific speed, pumps with large impeller inlet areas, or reduced flow operation in the region of suction recirculation. This means that a high percentage of pumps are operating with some degree of cavitation. It is the amount of Energy associated with the collapse of the cavitation bubbles that determines the degree of noise, vibration or damage from cavitation, if any.

Figure 4 shows the affect of the NPSH Margin Ratio on pump reliability, based on the 77 field pumps. Again, the Low suction Energy failures (below 48 months) were deleted, because it is unlikely that these failures were caused by

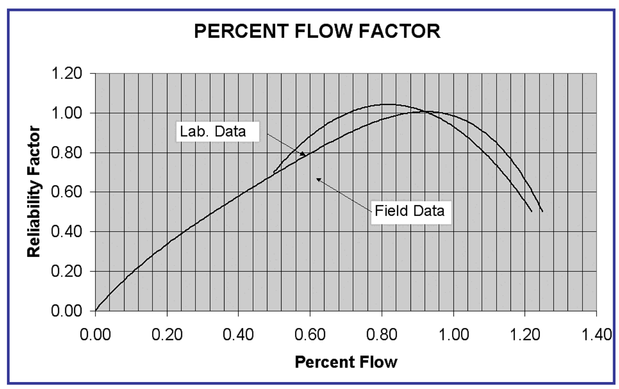


Figure 2.

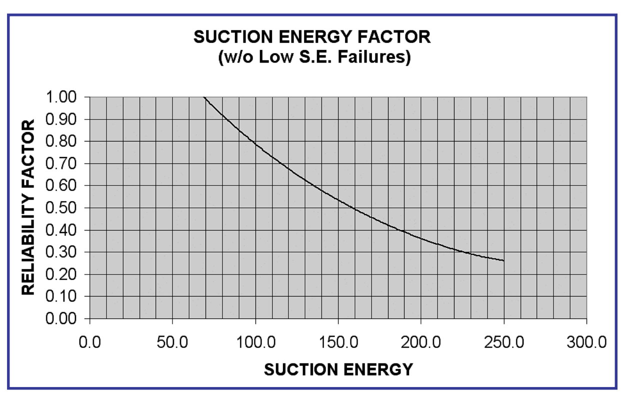


Figure 3.

Pump Reliability...

continued from page 2

factors related to Suction Energy, mainly cavitation. Based on this data, the NPSH Margin Ratio does have a definite influence on pump reliability, especially for High and Very High Suction Energy pumps, due to the fact that some cavitation usually exists below a Ratio of 4.0.

NPSH MARGIN RELIABILITY FACTOR:
The NPSH Margin Reliability Factor (Fig. 5) was developed to quantify the relationship between NPSH Margin and Suction Energy on pump reliability. The NPSH Margin Reliability Factors are based on the fact that, above the gating suction energy values (start of High Suction Energy), the greater the suction energy the more important it is to suppress the residual cavitation that exists above the NPSHR, to prevent damage. This reliability factor is only applicable within the allowable operating flow region, above the start of suction recirculation (see ref. 5). Much higher NPSH Margin values are required in the region of suction recirculation, for High and Very High Suction Energy pump applications.

The diagonal lines (in figure 5) are lines of constant relative Suction Energy (x 106). Therefore, (for example) the line marked "180/240" (Double Suction Suction Energy level / End Suction Suction Enegy level) represents the start of Very High Suction Energy. Pumps of this suction energy level require a minimum NPSH Margin Ratio of 2.5 for maximum reliability.

To validate the NPSH Margin Reliability Factors in figure 5, NPSH R.F. values were plotted against the field reliability of the 77 ANSI and Split Case pumps (without the 42 Low Suction Energy failures / below 48 months), as shown in figure 6. Although not perfect, the agreement is quite good. It must be remembered that the NPSH R.F. only applies to "High Suction Energy" and "Very High Suction Energy" pumps.

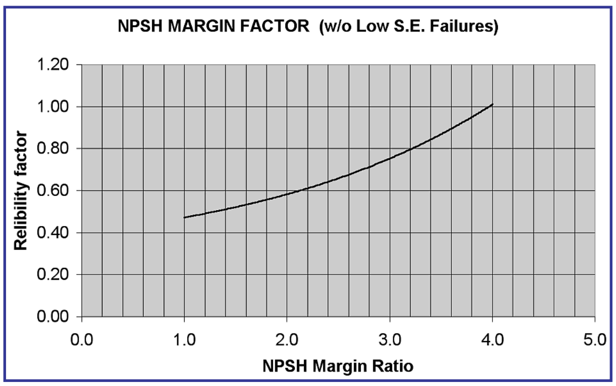


Figure 4.

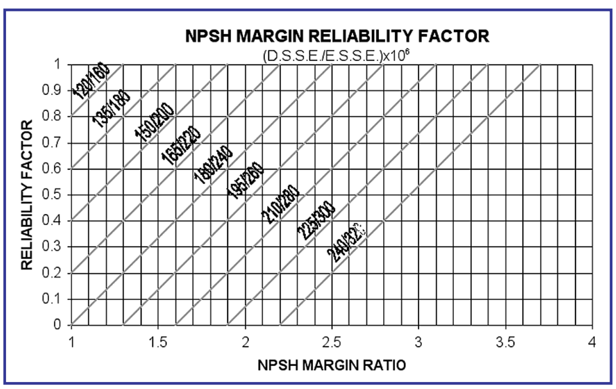


Figure 5.

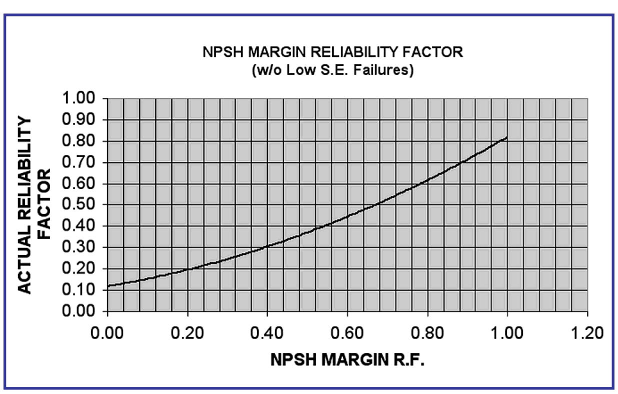


Figure 6.

CONCLUSIONS:

The speed,flow ratio,suction energy and NPSH margin reliability propositions and methodologies were confirmed by field experience.

The "Mean Time Between Repair" (MTBR) and Life Cycle Cost of most centrifugal pumps can be improved if slower pump speeds are used, and pumps are selected to operate in their preferred operating range (70% - 120% of bep flow rate – ref. 5).

Further, the Mean Time Between Repair of High and Very High Suction Energy pumps can be increased by keeping the NPSH Margin Ratio above the values recommended in figure 5, and/or by reducing the Suction Energy Level. The easiest way to lower the Suction Energy and increase the NPSH Margin of a pump application is by lowering the speed of the pump.

REFERENCES:

1. Erickson, R. B., Sabini E. P. and Stavale, A. E., October 2000, *"Hydraulic Selection to Minimize the Unscheduled Maintenance Portion of Life Cycle Cost,"* Pump Users International Forum 2000, Karlsruhe, Germany.

2. Bloch, H.P. and Geitner, F. K., 1994, *"An Introduction to Machinery Reliability Assessment,"* Gulf Publishing Company, Houston, TX.

3. Budris, A. R. and Mayleben, P. A., 1998, *"Effects of Entrained Air, NPSH Margin, and Suction Piping on Cavitation in Centrifugal Pumps,"* International Pump Users Symposium proceedings, Texas A&M University, Houston, TX.

4. ANSI/HI 9.6.1 – 2000, *"Centrifugal and Vertical Pumps for NPSH Margin,"* Hydraulic Institute, Parsippany, NJ.

5. ANSI/HI 9.6.3 – 2000, *"Centrifugal and Vertical Pumps for Allowable Operating Region,"* Hydraulic Institute, Parsippany, NJ